

FAR-FIELD ANTENNA PATTERNS DETERMINED FROM INFRARED HOLOGRAMS*

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INTRODUCTION

In this paper, we describe a technique based on optical holography which allows determination of the amplitude and phase of an unknown antenna on a near-field plane from amplitude-only measurements. We measure the interference pattern between the fields radiated by the antenna under test (AUT) and a known reference field. The reference field is produced by a standard gain horn radiating at an angle to the AUT and positioned so that the peak of the radiation occurs approximately at the same place as the peak from the AUT. The fields are detected by a resistive screen which absorbs some of the incident energy and heats as a function of the electric field intensity distribution. We use an infrared camera to record the temperature distribution caused by the interference of microwave energy radiated by the reference and the AUT. Data are processed using an enhanced algorithm based on conventional holography for recovery of the complex near field [1]. The new algorithm allows elimination of the spurious images commonly present in optical hologram readouts using illumination of the hologram with the reference wave.

THEORY

An optical hologram [2] is an interference pattern between an object wavefront and a reference wave, which is often assumed to be a plane wave. The interference pattern is commonly recorded with photographic film to form the hologram. Several wavefronts are produced when the hologram is illuminated by a replica of the reference wave. These can be identified as a virtual image of the object, a real image of the object, and a distorted version of the reference wave. An off-axis reference wave allows spatial separation of these three images. In antenna applications, this spatial separation is not sufficient because of the relatively broad pattern of the AUT and the large region of interest; the various images remain confused. In our scheme, the hologram is recorded digitally and processed so that the two spurious images are completely removed.

The hologram can be represented mathematically as the amplitude of the square of the sum of two fields [2]. The enhanced analysis uses a modified hologram

$$H = 2(|E_o|^2 - |E_r|^2 - |E_s|^2), \quad (1)$$

where

E_o = electric field of the AUT at the measurement plane with no reference wave present,

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E_r = electric field of the reference at the measurement plane, and
 E_a^2 = electric energy density ($\times 377$) in the hologram plane.

Now we record two holograms $H_{(1)}$ and $H_{(2)}$ using two different reference waves $E_{r(1)}$ and $E_{r(2)}$. If the reference waves $E_{r(1)}$ and $E_{r(2)}$ have equal magnitudes at all points but differ in phase by 90° , the antenna field E_a may be found from the modified holograms and the reference fields using [1]

$$E_a = \frac{j}{2|E_r|^2} (H_{(1)}E_{r(2)} - H_{(2)}E_{r(1)}) \quad (2)$$

EXPERIMENTAL DETAILS

Measurements were made at Rome Laboratory on a 36 element (6×6) microstrip array at 4.0 GHz. This antenna has a beamwidth of approximately 15° and a gain of 22 dB. The reference antenna was a pyramidal horn that has a gain of approximately 22 dB. The horn was characterized using planar near-field scanning, which allows calculation of the magnitude and phase of the reference field at the measurement plane. Since the measurement plane for the infrared measurements was tilted with respect to the near-field measurement plane, back-transformed data were calculated at the intersection of the measurement plane and a sequence of planes parallel to the near-field scan plane [3].

The experimental setup is shown in Figure 1. The AUT is mounted parallel to the measurement plane, while the reference horn is tilted at an angle ψ with respect to the normal to the plane. The measurement plane is defined by a 1.5×1.5 m resistive screen made of carbon-loaded polyimide film such as is employed in laser printers and copiers. The power into each antenna was approximately 50 W. The temperature distribution on the measurement plane was measured using an infrared camera with a temperature resolution of 0.1 K and 256×256 pixels. The maximum temperature rise in the screen was approximately 20 K. The resistive screen was mounted horizontally in order to reduce the effects of convection, which can lead to severe "bleeding" from warm to cooler regions.

The pixel size at the screen was 0.946 cm or 0.126λ at the microwave frequency. After the image was cropped to include only the relevant portion, the image array was 148×136 pixels. Hence the effective near-field scan area was 1.4×1.3 m.

After acquiring the thermal image of the resistive screen, we convert the temperature distribution to incident electric field [4,5].

RESULTS OF MEASUREMENTS

Data were acquired using the system of Figure 1 for incidence angles ψ of 29° and 44° and for three values of relative AUT to reference antenna excitation amplitude. In addition to the necessary holograms, we recorded patterns for the AUT alone and the reference antenna alone. As seen from Eq. (1), the enhanced algorithm also requires measurement of the intensity for the AUT alone. We could obtain the horn amplitude from the transformed near-field; however, we chose to use the infrared-recorded horn pattern. Recording the horn pattern thermally also allows us to compare the calculated magnitude with the measured magnitude.

Figure 2 shows a comparison of E-plane cuts for the AUT determined from standard planar near-field measurements and from the holographic measurement. There is good correspondence between the two measurements for the main beam and first principal sidelobes. There is some relative shift in the location of the main beam in the two patterns, because it was not possible with the current apparatus to maintain exact parallelism between the screen and the AUT surface. Such an offset is not deemed to be a significant problem since it is purely mechanical. Further, there was considerable sag in the recording screen, amounting to about a half-wavelength. This translates into an effective position error in the measured data. Beyond the first sidelobes, the holographically measured far field essentially washes out. Since the dynamic range of the overall measurement is approximately 20 to 25 dB, the effective scan area is approximately 80 cm in diameter. This results in truncation of the far-field region of validity to about $\pm 23^\circ$ or $|k_x/k| < 0.39$.

DISCUSSION AND CONCLUSIONS

We have demonstrated the feasibility of determining antenna far-field patterns using thermal imaging combined with holographic processing. The method shows promise for applications since the data acquisition is rapid and would lend itself to "quick and dirty" testing. In addition to the problems of registration and sag, there was also some interaction between the AUT and reference antenna which caused the relative power levels to shift slightly as the relative phase was varied. The major drawback to the technique is currently the limited dynamic range of the recording system, approximately 20 to 25 dB. Advances in infrared camera technology also show promise for increasing the dynamic range. Research is underway to compare the theoretical calculation of the field from screen temperature to measurements using well characterized incident fields.

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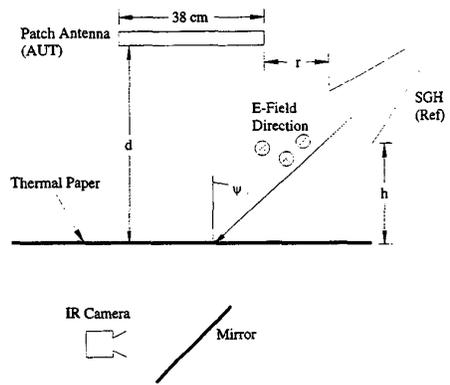


Figure 1: Experimental setup for infrared holographic measurement of antenna near field.

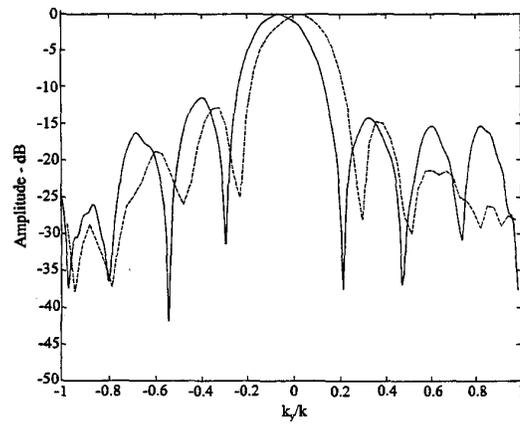


Figure 2: Comparison of far-field E-plane cut determined using near-field measurements (solid line) and using infrared holography (dashed line).